

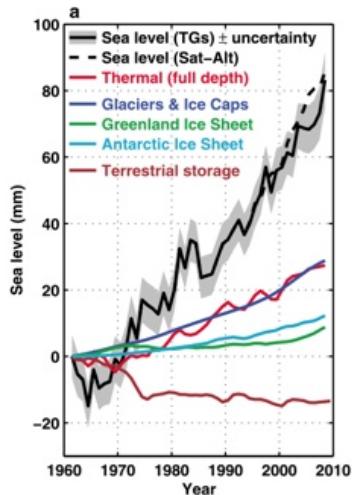
Mining declassified imagery to determine arctic glaciers
contribution to sea level rise since the 1970s.

Amaury Dehecq¹, Alex Gardner¹, Oleg Alexandrov², Scott McMichael²

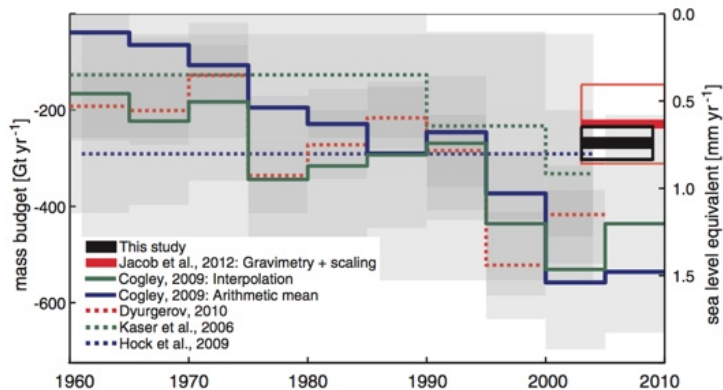
¹NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

²NASA Ames Research Center, Moffet Field, CA

Glaciers contribution to Sea Level Rise (SLR)



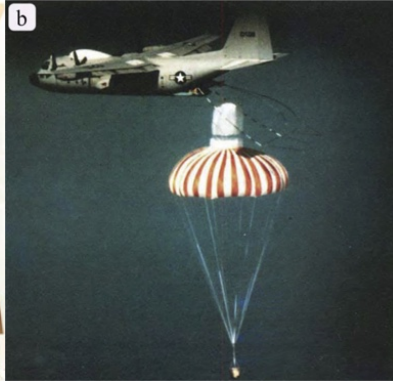
[Church et al., 2011]



[Gardner et al., 2013]

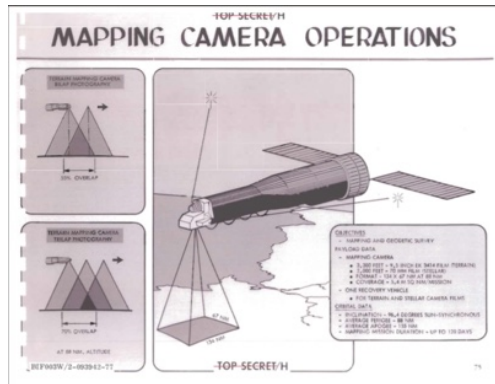
Hexagon (KH-9) - Characteristics

- 20 "spy" satellites launched from 1971 to 1986
- 4 re-entry capsules ("buckets") snatched mid-air (100 km of film)
- 12/20 included mapping camera : 6-9 m resolution - $250 \times 125 \text{ km}^2$



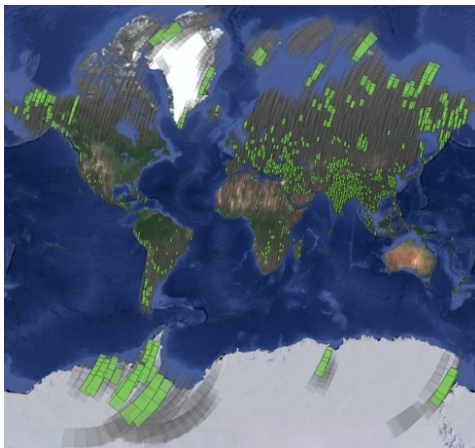
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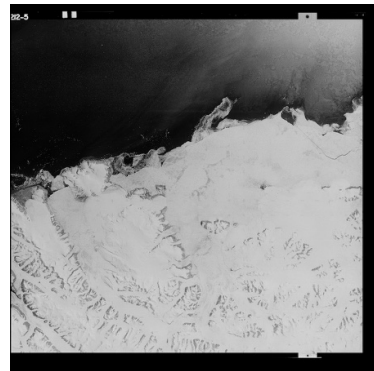
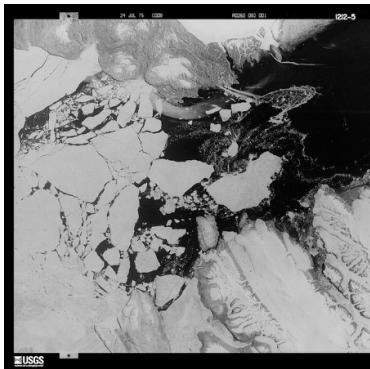
KH-9 data - Mapping camera coverage

- 29 000 images available
- ~ 2 200 currently scanned by the USGS
- 1 875 over glaciers



KH-9 data - Challenges

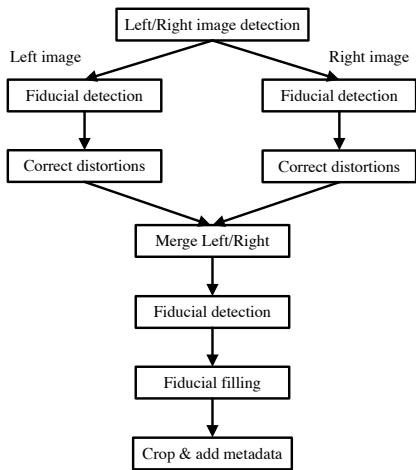
- Images on 46 cm x 23 cm film \Rightarrow scanned in two separate images (66.000 x 33.000 pixels at 7 μm)
- Distortion due to 40-year storage and scanning
- Satellite position still classified



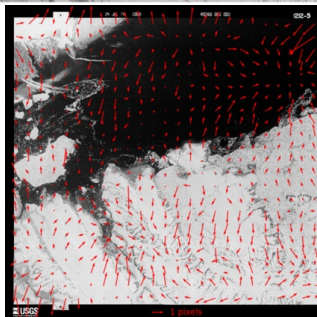
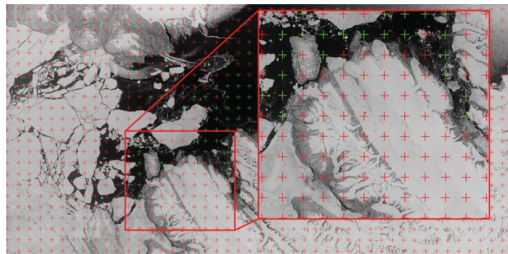
BUT

- 47 x 23 grid of regularly spaced fiducial markers (reseau plate)
- crude corner geolocation provided by the USGS (several km accuracy)

Preprocessing



Fully automated work-flow.

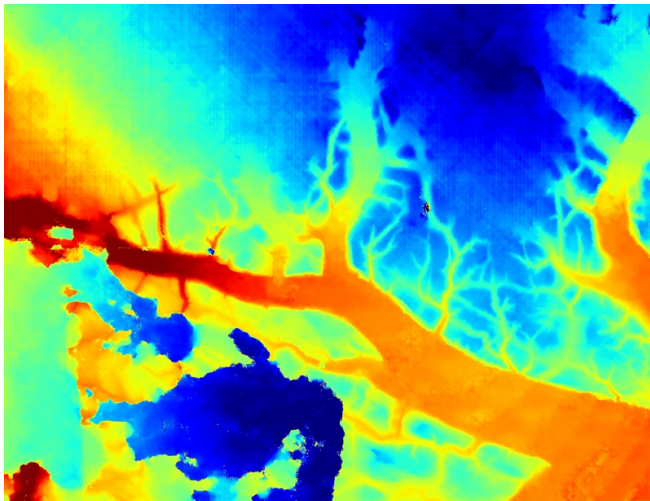


Preprocessing

> 300 images pre-processed automatically !

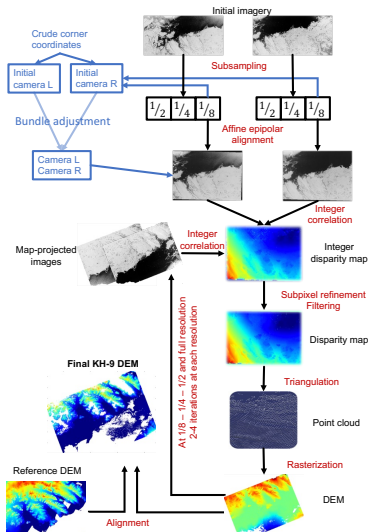
Stereo processing - Overview

Stereo processing - Overview



Disparity map

Stereo processing - Overview



Processing with NASA Ames Stereo Pipeline (ASP).

Solving for camera position (without control point !) :

- (1) Initial estimate from image corners provided by USGS,
- (2) Bundle adjustment ensures consistency between left/right images,
- (3) Generate an initial DEM (can be several km off)
- (4) Alignment with reference DEM to update camera positions.

Stereo :

- SGM with kernel of size $7 \times 7 \Rightarrow$ disparity map
- triangulation \Rightarrow point-cloud and DEM
- processed iteratively at increasing resolution
- final DEM aligned with reference DEM using Iterative Closest Point (ICP)

Elevation change and mass balance

Elevation changes are calculated with reference to ArcticDEM v2.0 (Polar Geospatial Center under NSF awards) :

1. DEMs are aligned at subpixel level using Nuth & Kääb algorithm
2. DEMs are differenced and converted to annual rates using individual time stamps (currently KH-9 only)
3. Remaining large scale distortions are removed using a 2D polynomial of degree 2 off-ice

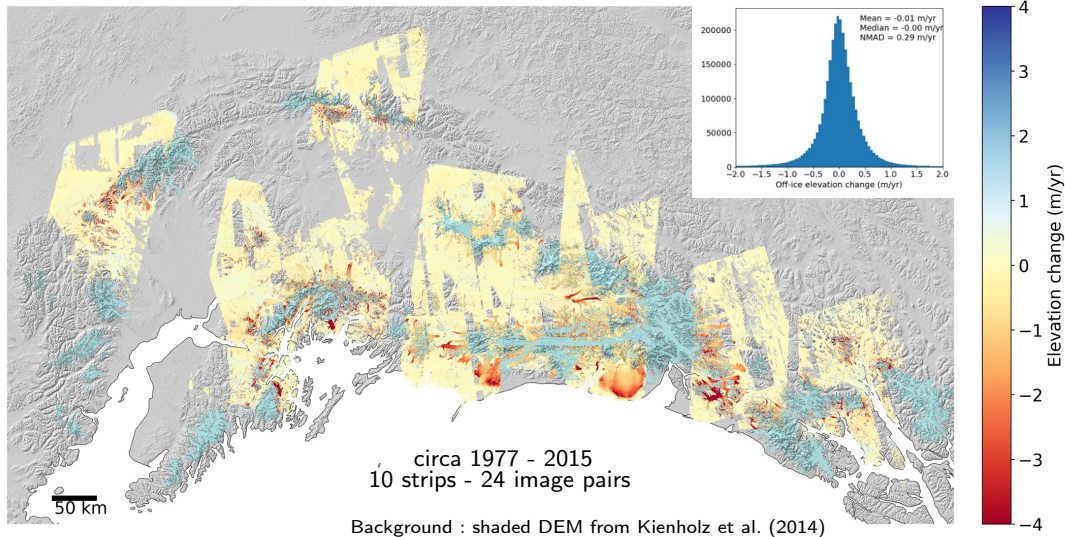
Region-wide mass balance :

1. An elevation-dependent change rate is calculated for 50 m elevation bins.
2. The rate is multiplied by glacier hypsometry to derive a volume change, therefore accounting for gaps in dhdt maps.

Results - Alaska

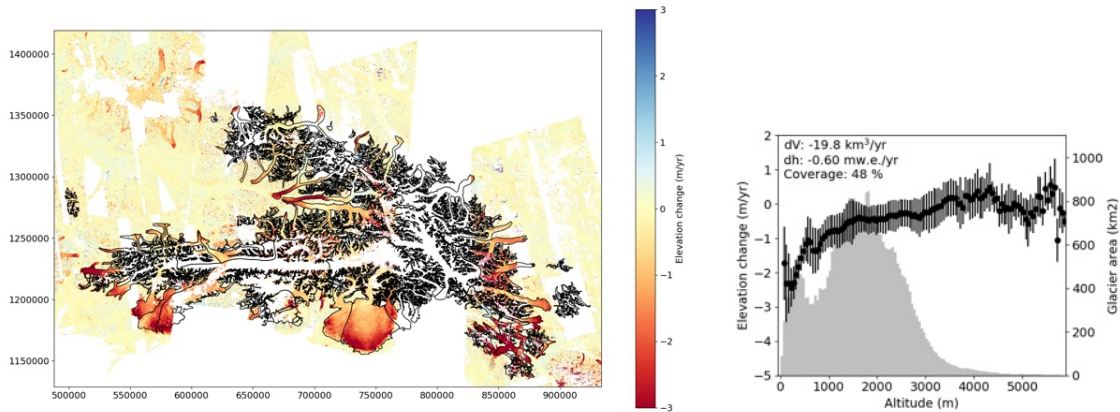
Slide to present Alaska glaciers

Results - Alaska



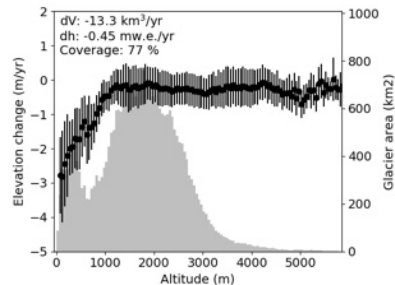
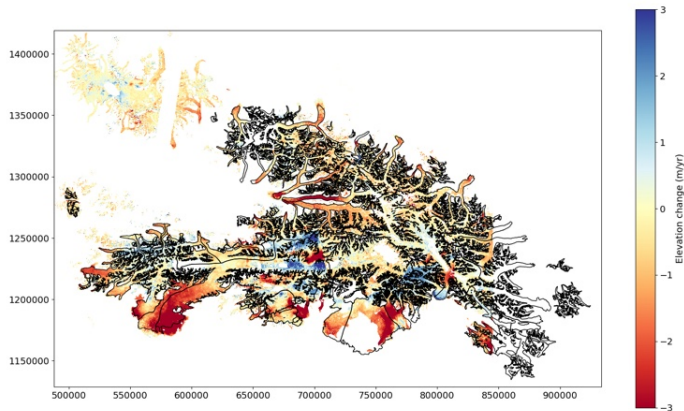
Results - Alaska

St Elias range - Hexagon vs ArcticDEM (1977 - 2014)



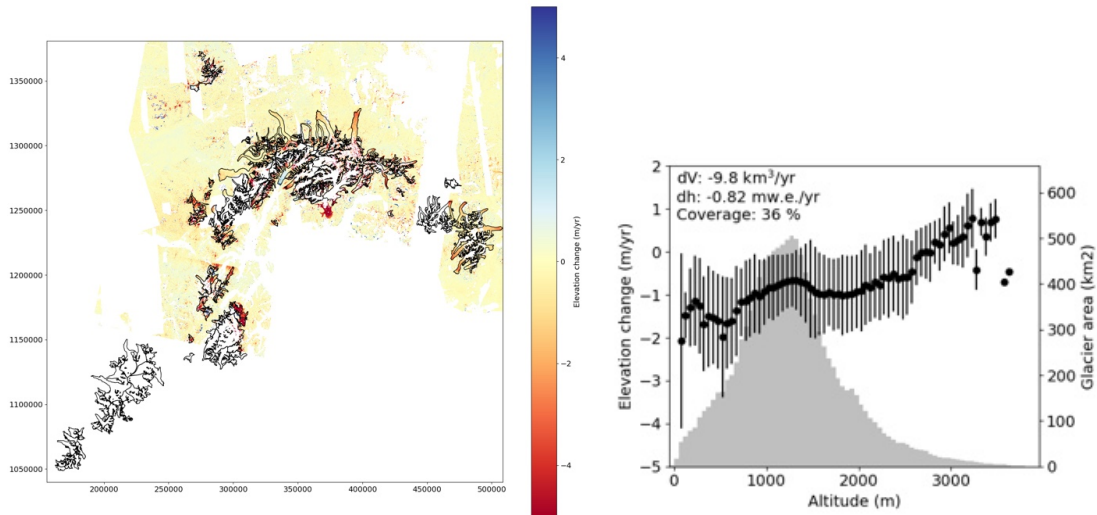
Results - Alaska

St Elias range - From Berthier et al., 2010 (1968 - 2006)



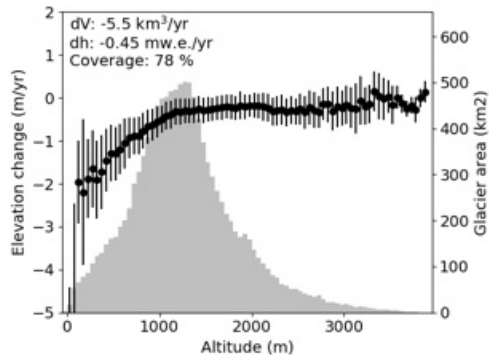
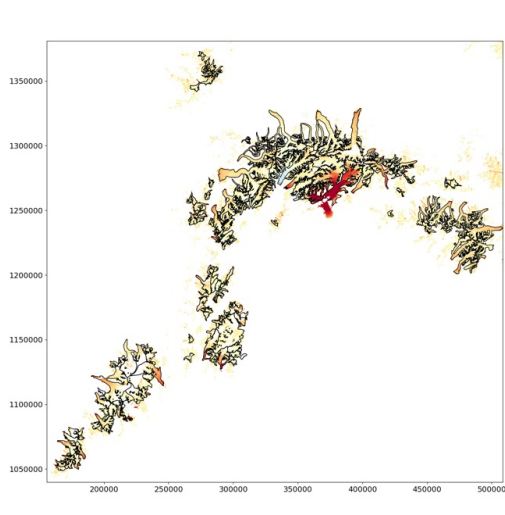
Results - Alaska

Western Chugach - Hexagon vs ArcticDEM (1977 - 2014)

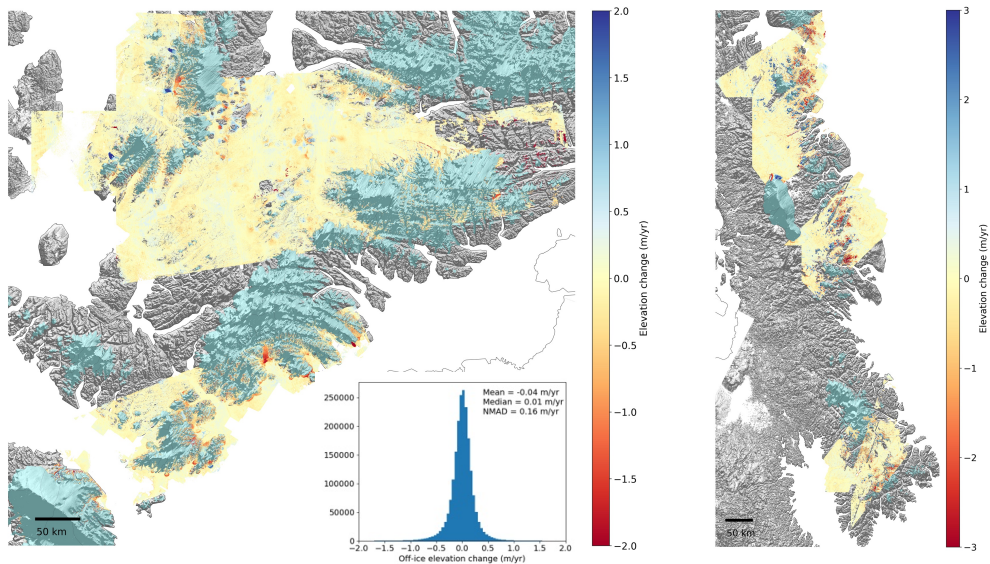


Results - Alaska

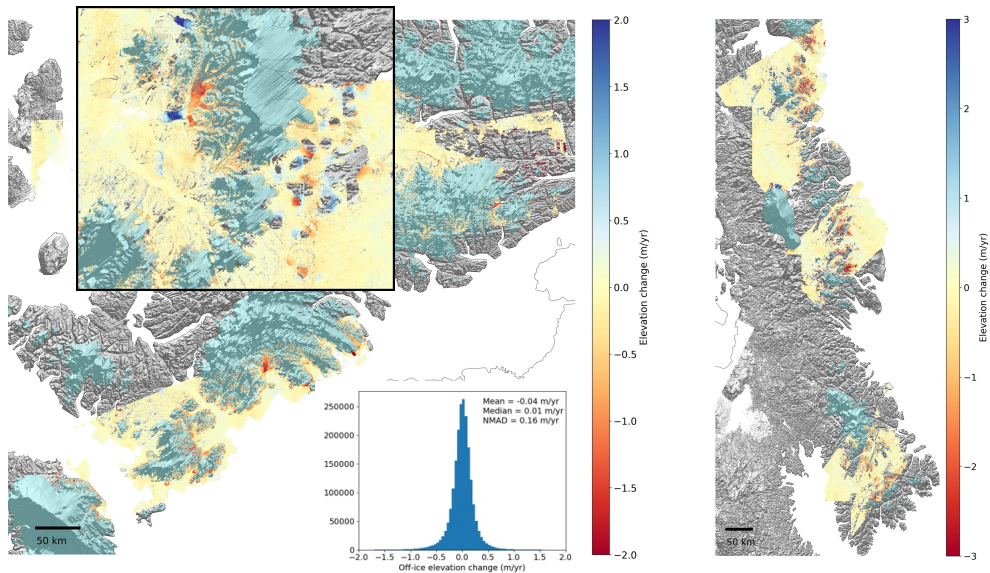
Western Chugach - From Berthier et al., 2010 (1954 - 2006)



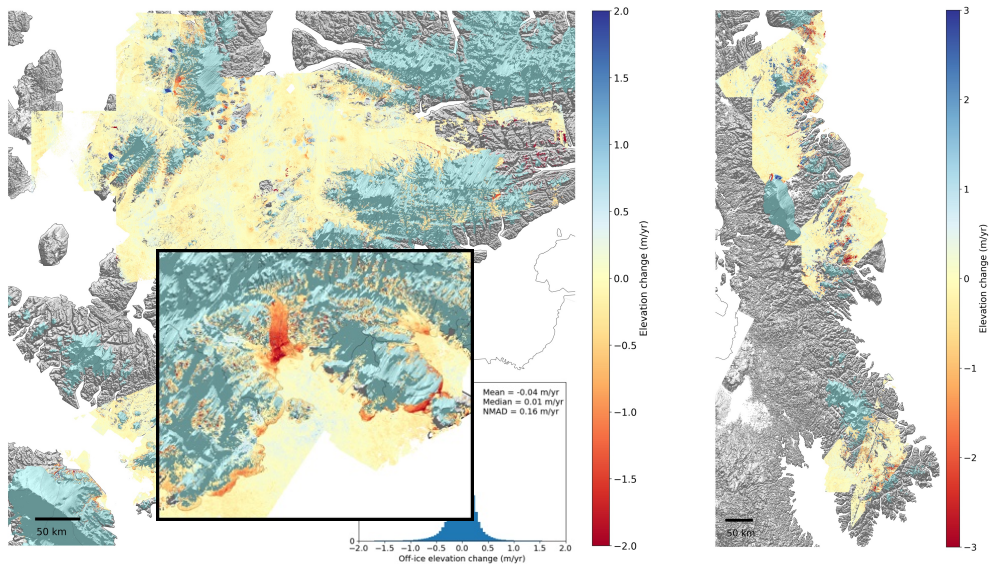
Results - Canadian arctic



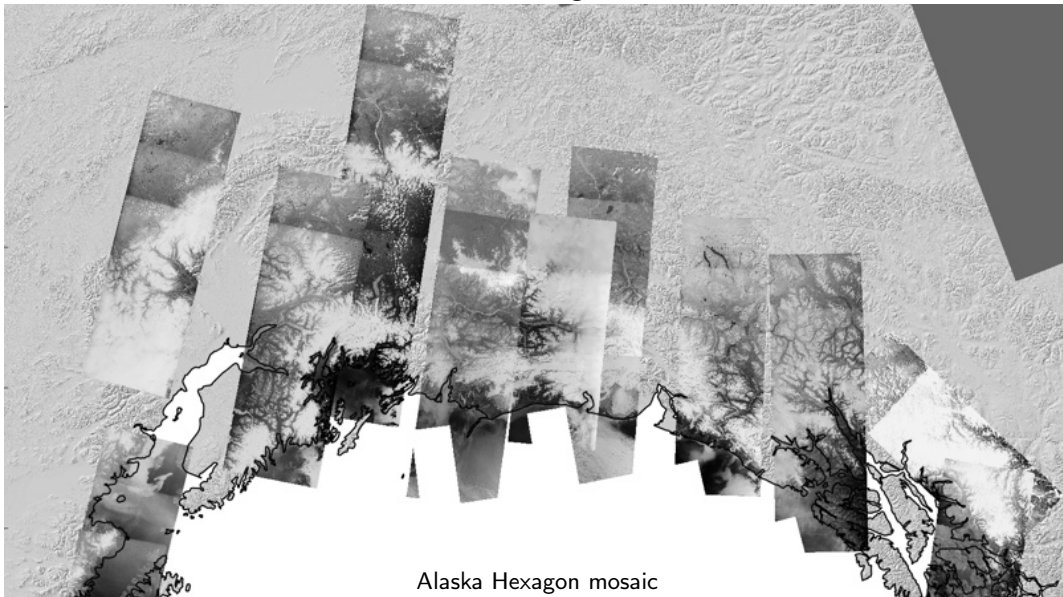
Results - Canadian arctic



Results - Canadian arctic



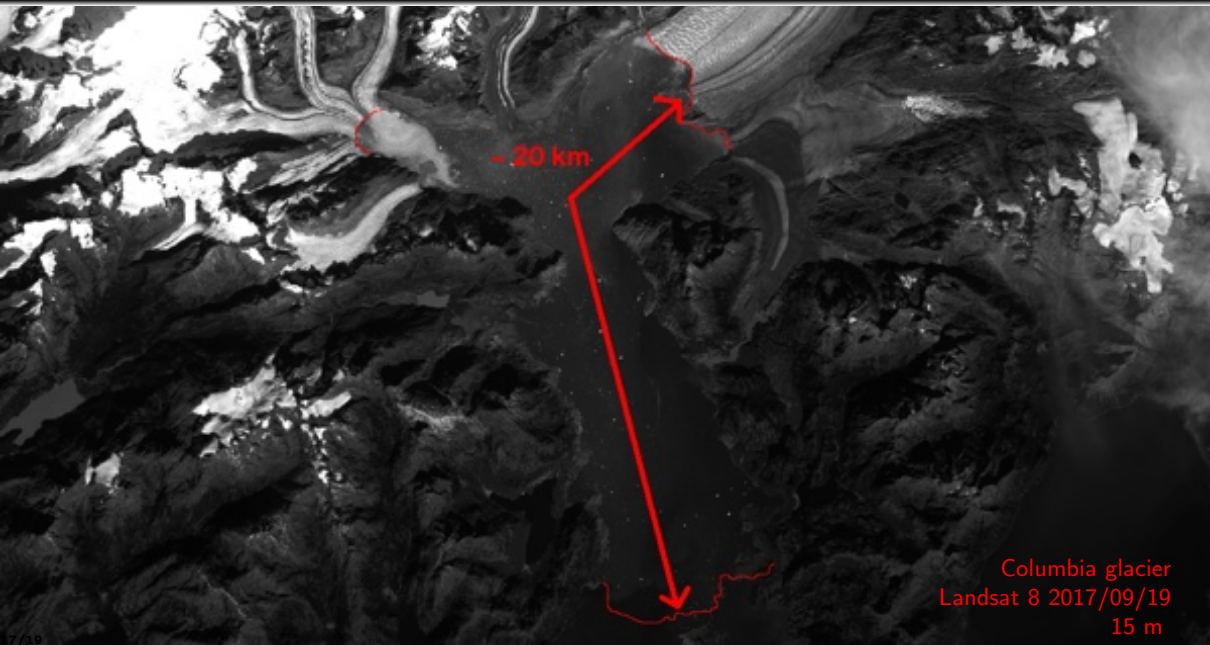
Ortho images



Alaska Hexagon mosaic

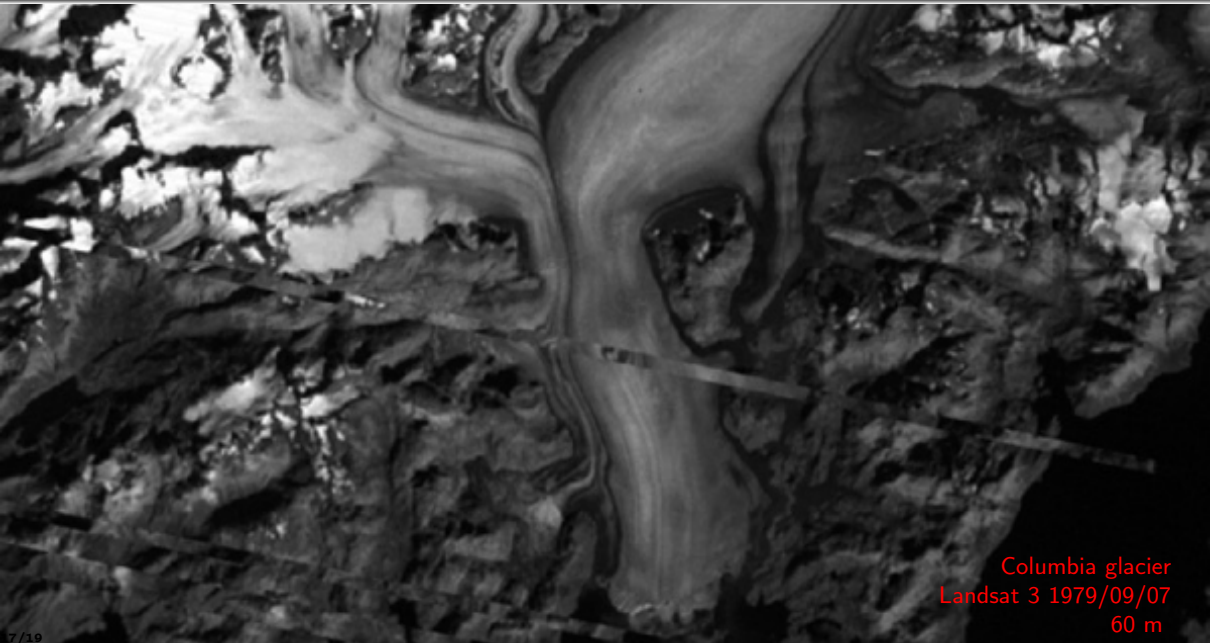


Columbia glacier
Hexagon 1979/06/15
6 m

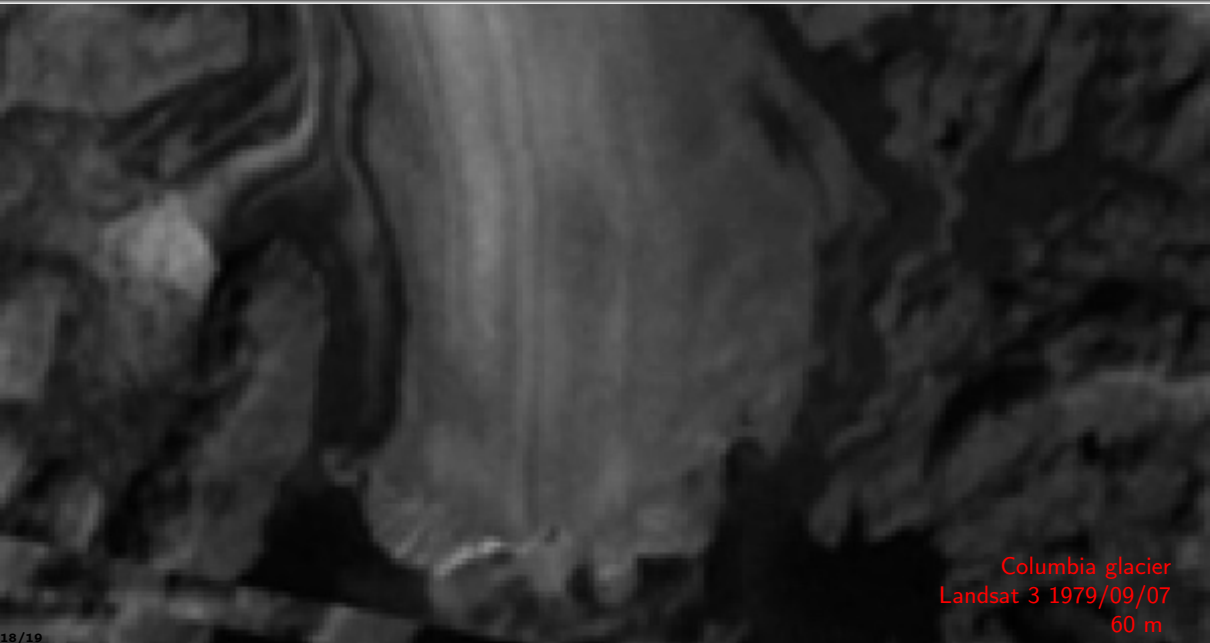


- 20 km

Columbia glacier
Landsat 8 2017/09/19
15 m



Columbia glacier
Landsat 3 1979/09/07
60 m



Columbia glacier
Landsat 3 1979/09/07
60 m



Columbia glacier
Hexagon 1979/06/15
6 m

Conclusions

Conclusions

- Good potential of the KH-9 image for deriving regional glacier volume changes.
- Application to Alaska glacier (St Elias + Western Chugach) yield a total volume change of 1095 km³ or 3.0 mm SLE for the period 1977 - 2015, in good agreement with previous studies.
- Ortho-images represent a valuable data set for the observation of surface changes.

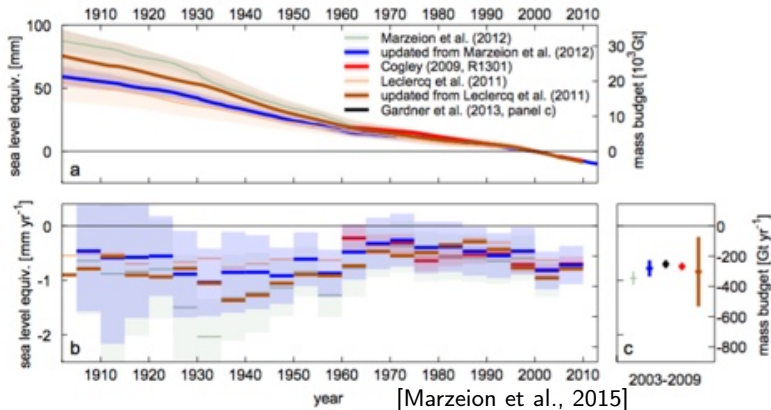
Perspectives

- Process more data !
- Improve results over low-contrast terrain.
- Estimate uncertainties.
- Extend work to other regions.

Thank you for your attention
(Your memory will now be erased... after the questions!)



Where do these results come from ?



- Global/regional satellite obs. (ICESat, GRACE, SRTM,...) since ~ 2000
- Glaciological (field-based) glacier mass balance of ~ 200 glaciers since 1960'
- Reconstruction from glacier length and/or modelling for the 20th century